FINAL REPORT

Title: A multi-proxy approach to understand forested peatland fire regimes at scales relevant to management

JFSP PROJECT ID: 19-1-01-35

AUGUST 2021

Volker C. Radeloff
University of Wisconsin-Madison, Department of Forest and Wildlife Ecology

Sara C. Hotchkiss
University of Wisconsin-Madison, Nelson Institute for Environmental Studies

Jed Meunier
Wisconsin Department of Natural Resources, Division of Forestry

Colleen M. Sutheimer
University of Wisconsin-Madison, Department of Forest and Wildlife Ecology

Table of Contents

List of tables

List of figures

List of Abbreviations

CE – Common Era
DNR – Department of Natural Resources
JFSP – Joint Fire Science Program
MNFI – Michigan Natural Features Inventory
NHC – Natural Heritage Conservation
PDSI – Palmer Drought Severity Index
USFS – United States Forest Service
USGS – United States Geological Survey
spp. – species

Keywords

Multi-proxy; Paleoecology; Dendrochronology; Fire history; Fire regime; *Pinus resinosa*; Great Lakes Region; Lake States; Temperate peatlands

Acknowledgements

This work was supported by the Wisconsin Department of Natural Resources, Division of Forestry, Applied Forestry, Forest Economics and Ecology Section, the US Department of Agriculture Forest Service, and the Lake States Fire Science Consortium. We are grateful for correspondence with J. Cohen, E. Epstein, J. Lampereur, S. Linn, R. O'Connor, M. Sebasky, R. Swaty, and J. Saunders all of whom provided important information during site reconnaissance. We are indebted to USFS fire management officers E. Rebitzke, S. Barnes, B. Dale, S. Duerksen, and T. Sauter for their logistical support in the Hiawatha and Chequamegon-Nicolet National Forests. We also acknowledge those who helped us collect data including M. Heritsch, C. Kaplon, M. Sebasky, and I. Widick, and the assistance from J. Riser and C. Guiterman. We also want to thank our collaborators at Michigan Technological University, Dr. Rod Chimner, Dr. Evan Kane, and Dr. Dominic Uhelski who conducted the peat sediment collection and analysis work.

Abstract

Fire was one of the most ubiquitous disturbances across the Lake States prior to European settlement, however, the historical range of variability in fire regimes of the Lake States is poorly understood especially in systems like peatlands which are assumed to be fire infrequent. Fire regimes across the Lake States and in peatlands have been reconstructed with methods best suited for understanding high-severity fires that burned across large regions of continuous fuels while frequent low-severity surface fires have been largely missed. We used a multi-proxy approach to reconstruct fire histories among peatlands in the Lake States with lake sediment cores, peat cores, and fire-scarred tree samples. We established that different methodologies contribute to disparity in historical fire return intervals reported in peatlands and that multi-proxy methods are key to fully characterizing historical fire regimes. Fire chronologies were longest for peat and lake sediment records (>1000 years) with course temporal resolution (20 to 200 year fire periods) and shorter for tree-ring records (>100 years) with fine temporal resolution (year and season of single fire event). Mean fire return intervals ranged from 95 to 704 years in the lake sediment record, ranged from 324 to 392 years in the peat records, and ranged from 7 to 27 years in the tree-ring record. Historically, climate synchronized fire events in peatlands with low- and moderate-severity fire events detected in the tree-ring record rarely corresponding to severe drought conditions. We examined correspondence between data sets of historical fire regimes in the Lake States at varying spatial, temporal, and biophysical extents within sites and across large landscapes which is essential to providing guidance to managers at relevant scales. While prescribed fire has been widely adopted in prairies and savannas throughout the Lake States, its use in other ecosystems like peatlands and forests has been minimal in part because of a lack of understanding of fire ecology in these systems. Our research supports the use of prescribed fire across the Lake States and indicates that prescribed fire could contribute to the persistence of ecosystems including poor fens and mixed-pine forests at the landscape scale and fire-dependent species like red pine at the stand level. We have provided a better understanding of fire ecology in the Lake States generally and peatlands specifically equipping managers and policy makers across the region with new information to better restore, conserve, and manage the unique ecosystems of the Lake States. Extensive networks that include tree-ring, sediment, and historical records establish historical ranges of variability in disturbance regimes within and among ecosystems revealing the influence of both local and broad scale drivers on fire regimes. Integrating these records with predictive models will provide the best insights to the capacity of ecosystems to recover and persist under broad scale, highly variable climate changes.

Objectives

We used a multi-proxy approach to reconstruct forested peatland fires comparing tree-ring based reconstructions to radiocarbon dating of char within peat and lake sediment cores to calibrate evidence of local fires and distinguish local signals from background char accumulation (e.g., what is a “big fire year”?). This work contributed to foundational understanding of fire history, fire effects, fuels management and fire behavior in forested peatlands directly, and the Lake States generally, to better understand relative impacts of prescribed fire versus wildfire. A hands-off approach to management in forested peatlands has largely rested on untested assumptions. We collected data that calibrated paleo (sediment-char) and tree-ring fire data both temporally and spatially, providing benchmarks useful to management. Our data is instrumental for wildfire risk assessments, locally and regionally. It was hypothesized previously that peat fires were historically infrequent and connected to extreme conditions (drought and severe fires). Our objectives were to (1) develop regional fire history, including peatlands, by adding lake sediment and peat core analysis to a comparison of detailed fire reconstruction methods and (2) identify climate-fire interactions across spatial and temporal scales.

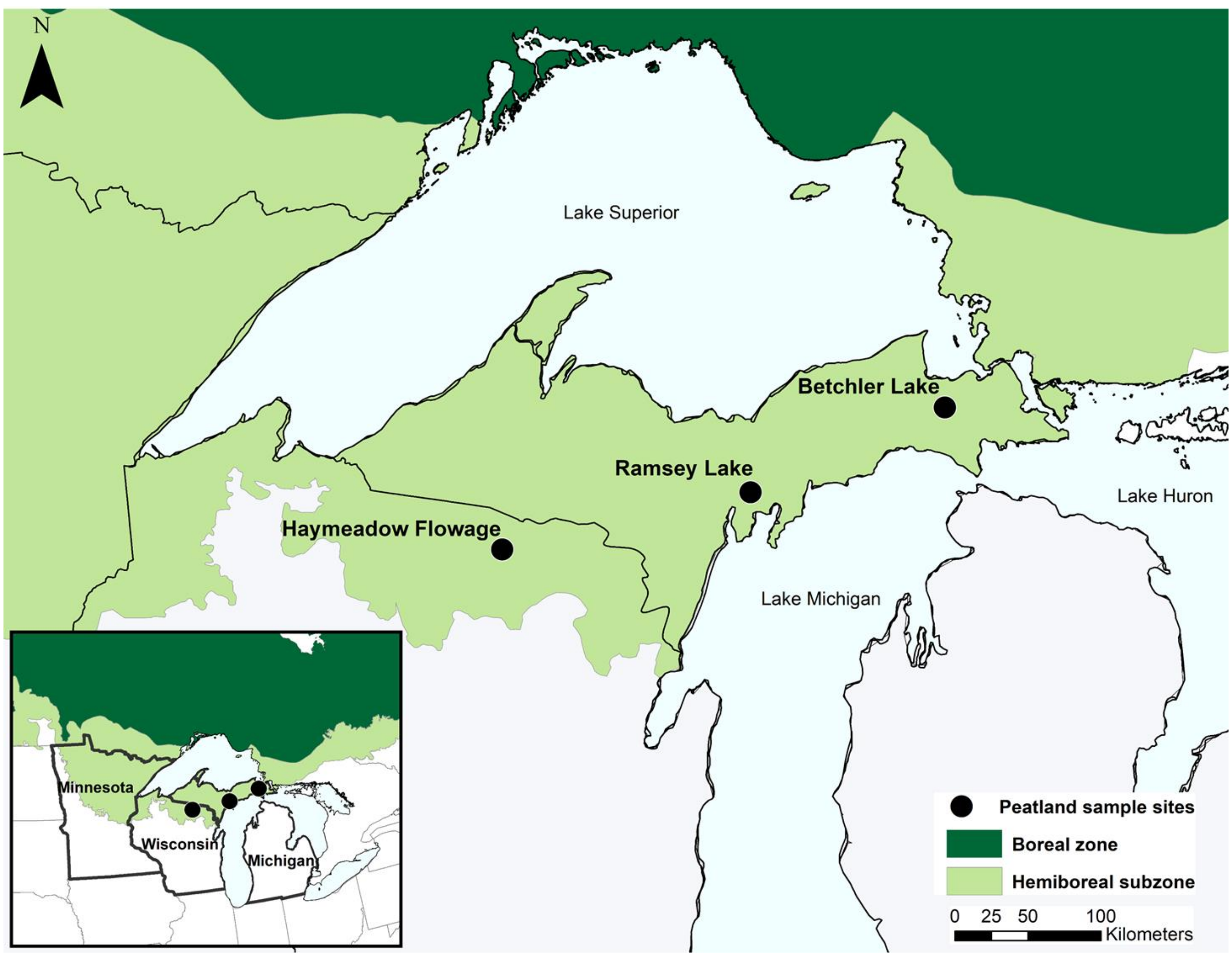

Fig. 1 Locations of peatland sample sites across the Lake States (inset) in North America with the true boreal and hemiboreal subzones (see Brandt 2009) differentiated.

Background

The Lakes States contain >14 million acres of peatlands and have recently experienced some of the highest rates of decline in the US (Dahl 2011). Peatlands are notoriously difficult to regenerate and aside from limited harvest and fire suppression activities management has largely been hands off. In addition, fires in forested peatlands are some of the most problematic and expensive fires. Despite all of this, Lake States land managers have little and often contradictory information about the ecology and silviculture of these systems.

Significant land use changes after European settlement resulted in homogenization of landscapes across the Lake States (Frelich 1995; Schulte *et al*. 2007; Goring *et al*. 2016) and without historical context it is unknown how projected climate change and climate variability will influence the severity and frequency of disturbances across the Lake States (Pryor 2013; Sturrock *et al*. 2011; Easterling *et al*. 2017). Ecosystem resilience, or the capacity of an ecosystem to recover after disturbance, is maintained over centuries as adaptations develop under disturbance regimes and resilience erodes when disturbance regimes are outside of the historical range of variability (Johnstone *et al*. 2016). Disturbance regime characteristics (e.g., frequency, extent, severity) in conjunction with climate, topography, vegetative structure, and species composition, contribute to highly complex and regionally variable disturbance regimes (Wein *et al*. 1983, Zoltai *et al*. 1998).

Fire was one of the most ubiquitous disturbances across the Lake States prior to European settlement (Whitney 1986, Schulte and Mladenoff 2005). However, due to a paucity of data related to historical fire regimes, the historical range of variability in fire regimes among diverse ecosystems of the Lake States is poorly understood (Heinselman 1963, 1973, Bergeron *et al*. 2004*a*). Fire regimes across Lake States have generally been reconstructed with sediment records (Booth and Jackson 2003, Booth *et al*. 2004) or settlement surveyor data (Whitney 1986, Cleland *et al*. 2004, Schulte and Mladenoff 2005). These methods are best suited for understanding high-severity fires that burned across large regions of continuous fuels (Cyr *et al*. 2007, Kelly *et al*. 2013). Dendrochronology approaches can reconstruct frequent low-severity surface fires that are largely missed in sediment charcoal records and settlement surveyor data (Higuera *et al*. 2011, Remy *et al*. 2018). Reconstructing historical disturbance regimes across multiple spatial scales, among diverse ecosystems, and over continuous temporal records provides the best evidence of historical ranges in variability (Schulte and Mladenoff 2005; Falk *et al*. 2011; Swetnam *et al*. 2016).

In the Lake States, the concept of fire rotation more than any other metric has been used to define fire regimes (Van Wagner 1978, Cleland *et al*. 2004, Schulte and Mladenoff 2005). Johnson and Gutsell (1994) asserted that the use of fire rotation intervals is the only statistically valid method of reconstructing fire events because it accounts for spatial and temporal variability. Rotation intervals have mostly been applied at landscape scales using historical age distribution data and/or notes from Euro-settlement era surveyor data (Cleland 2004). However, these methods cannot capture low-severity fires that were historically much more common, and widespread, than commonly presumed (Drobyshev *et al*. 2008, Meunier *et al*. 2019 *a,b*). Moreover, species like tamarack and red pine have been shown to decline where stand-replacing fires dominated (Bergeron and Brisson 1990), also suggesting life history strategies of species across the Lake States include adaptations to low-severity fires (Drobyshev *et al*. 2008).

Paleo methods (e.g. charcoal analysis via sediments) often cover long-temporal scales and are regionally relevant but are not easily interpreted in a localized management scale or context (Remy 2018). It is increasingly recognized that charcoal signals for recent periods (<300 years) must be compared with historical or tree-ring methods to refine peak detection and evaluate reconstruction accuracy (Higuera *et al*. 2011, Brossier *et al*. 2014). Detecting and quantifying variability in fire regimes that include frequent low-severity fire and infrequent, high-severity fire is prerequisite to identifying ecological consequences of altered fire regimes (McLauchlan *et al.* 2020) and is possible through multi-proxy approaches that incorporate both tree-ring records and charcoal records.

Peatlands, perhaps more than any other ecosystems in the Lake States, are depauperate in historical information necessary for their management and conservation. Changes in composition, structure, and function of these ecosystems because of changes in fire regimes have received little attention from managers and researchers, yet the magnitude of changes may be unrivaled (Cleland *et al*. 2004). Afforestation may be causing peat fires to be more severe as increased tree size and abundance with lack of fire changes hydrology making the system more prone to drying which could result in deeper burning and more severe fires (Wilkinson *et al*. 2018). The need to Identify opportunities to jointly reduce fuel loadings on federal lands and safely reintroduce wildland fire is, and will likely remain, a priority (Barnett *et al*. 2016). In order to understand such changes, we need to understand historical fire conditions and ecology.

Materials and Methods

Study area

Our study area consisted of three sites (Haymeadow Flowage in Wisconsin, Upper Lost Lake in Michigan, and Betchler Lake in Michigan) across the Lake States characterized as poor fens intermixed with dry to dry-mesic forested uplands. Poor fens are weakly minerotrophic, acidic peatlands with shallow peat (1–3 meters), continuous saturation of soils from a stable water table, and often transition sedge- and rush-dominated northern fens and sphagnum dominated bogs (Cohen *et al*. 2015). Fine-leaved sedges (*Carex* spp.) and low shrubs including leatherleaf (*Chamaedaphne calyculata*), bog Labrador tea (*Ledum groenlandicum*), bog birch (*Betula pumila*), and other Ericaceae were prevalent in the peatland vegetation of our sites (Minnesota Department of Natural Resources 2003). Sphagnum (*Sphagnum* spp.) was also abundant with variable development of hummock formation. Overstory trees of forested portions of peatlands included scattered tamarack (Larix laricina) and black spruce (*Picea mariana*). Forested uplands within and surrounding peatlands were predominantly red pine (*Pinus resinosa*) with occasional white pine (*P. strobus*), jack pine (*P. banksiana*), and *Populus* spp. Understories were sparse, dominated by bracken fern (*Pteridium aquilinum*) and wintergreen (*Gaultheria procumbens*).

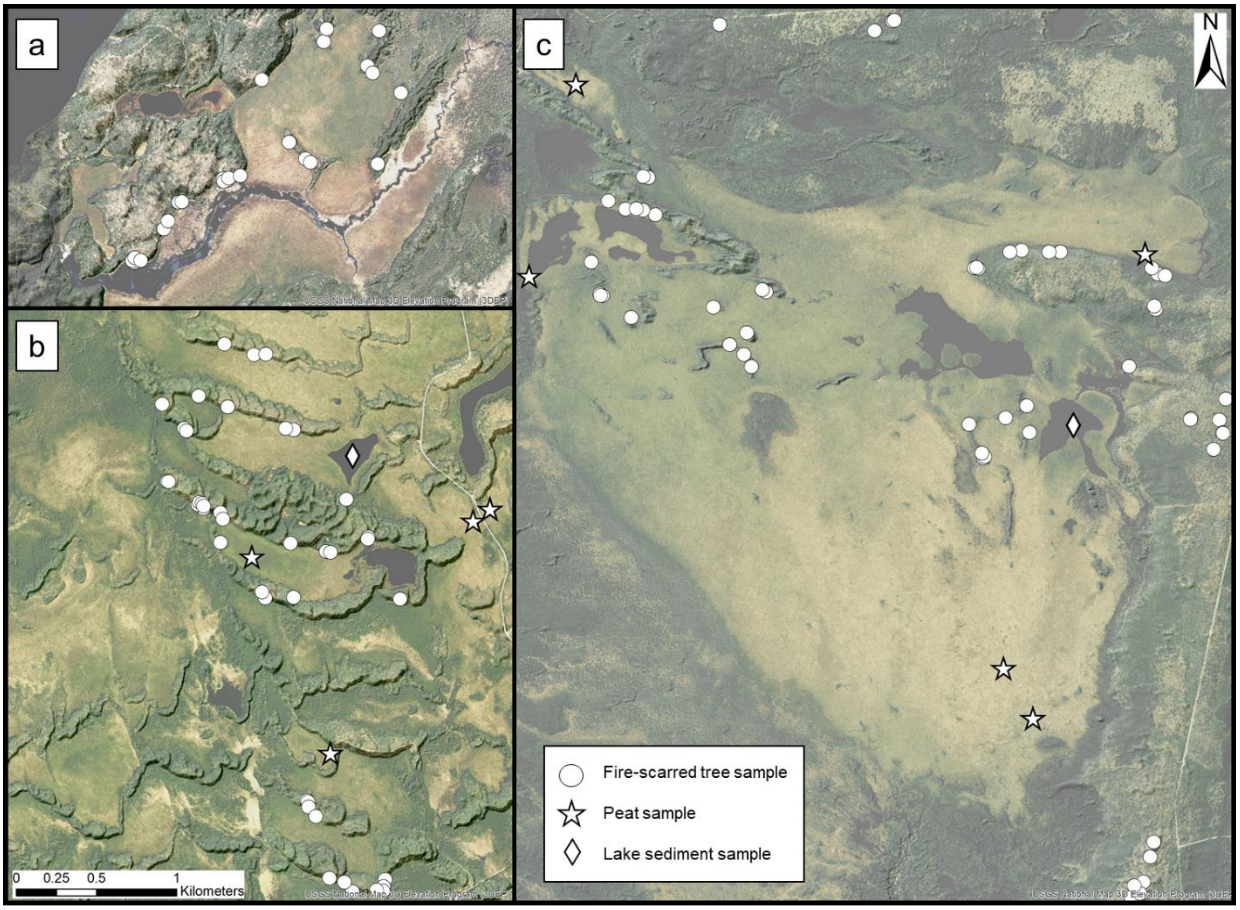

Fig. 2 Fire-scarred tree samples (circles) on forested uplands within and surrounding peatlands, peat core samples (stars), and lake sediment core samples (diamonds) for (a) Haymeadow Flowage, (b) Ramsey Lake, and (c) Betchler Lake. Leaf-off aerial imagery has been overlaid with the USGS 3D Elevation Program Bare Earth Dynamic Elevation Model to distinguish vegetational and topographical differences used to delineate forested uplands within and surrounding peatlands.

Data collection

From 2018 to 2019, we sampled forested uplands within and surrounding three hemiboreal peatlands in the Chequamegon-Nicolet and Hiawatha National Forests from northeastern Wisconsin to the eastern end of the upper peninsula of Michigan (Fig. 1) spanning ca. 320 km. Forested uplands within peatlands included conifer-dominated islands (uplands with topographic relief and surrounded by peatland) and ridges (long, narrow uplands within peatlands; Fig. 2). We collected cross sections of fire-scarred tree samples (Fig 3c) with chainsaws primarily from remnant red pine – and occasionally white or jack pine – stumps, i.e., trees that were harvested during the Lake States cutover period (ca. 1850–1920). We collected lake sediment cores (Fig 3a) in February 2020 for Lower Betchler Lake and Upper Lost Lake (Fig. 2b, c) using direct push piston drive corers. Dr. Dominic Uhelski, Michigan Technological University, collected peat cores (Fig. 3b) at the Betchler Lake and Upper Lost Lake sites (Fig. 2b, c) in 2018 using a direct push Russian peat borer.

Fig. 3 Lake sediment core (a), peat core with layers of macrocharcoal visible (b), and fire-scarred tree sample with catface and fires scars visible.

Data analysis

We used standard dendrochronological techniques to cross-date samples and assign exact calendar dates to all fire scars of fire-scarred tree samples (Grissino-Mayer and Swetnam 2000, Speer 2010). We used standard methods to prepare and sample lake sediment cores for evidence of fire events identified with charcoal (Jensen *et al*. 2007; Lynch *et al*. 2011, 2014). We sampled cores at 0.5 cm increments, sieved these contiguous increments to pull out charcoal larger than 125-microns, and examined charcoal pieces at each increment under a dissecting microscope to count total number of pieces and assign morphotypes (Fig. 8; Kaplon 2021). We used radiocarbon dating and Lead-210 dating to reconstruct age-depth models for lake sediment cores. Age-depth models were reconstructed using the rbacon package v.2.5.3 in R v.4.0.4 (Blaauw and Christen 2011) and used a Bayesian Markov Chain-Monte Carlo simulation framework with a prior assumption of stratigraphic superposition and the IntCal20 calibration curve for conversion of radiocarbon ages to calendar years (Reimer *et al*. 2020). Michigan Technological University collaborators prepared and analyzed peat strata to determine frequency of fire events using charcoal through multiple methods (Plante *et al*. 2009, Kane *et al*. 2010; Miesel *et al*. 2012; Uheslki 2021).

We conducted multi-proxy analysis (tree-rings, peat sediments, lake sediments) for reconstructing fire regimes for peatland sites at a multitude of spatial and temporal scales. We compared length of chronologies, number of fire events detected, and mean fire return intervals among fire-scarred tree samples, peat core samples, and lake sediment core samples. We identified fire events and estimated mean fire return intervals in the tree-ring record by filtering to identify synchronous, and more widespread, fire years. Level of filtering provides evidence of more widespread fires by selecting only fire events that are recorded by multiple samples at a study site (Farris *et al*. 2010, 2013, Meunier and Shea 2020). We assumed that synchronous fire years on multiple forested uplands (within and surrounding peatland sites) were indicative of widespread fire events that burned across peatland landscapes and contributed to fire events detected in the lake sediment and peat cores.

We analyzed fire events in lake sediment cores by identifying peaks in charcoal accumulation rates outside of baseline levels of charcoal accumulation that result from continuous washing in of sediments into lake basins. We applied a locally weighted (LOESS) smoothing model to charcoal accumulation rates using a 500-year moving window to identify peak charcoal accumulation rates (Higuera *et al*. 2010). A value of 0.5 was chosen to represent the threshold at which the difference between the observed charcoal accumulation rate and the background charcoal accumulation rate (locally weighted smoothing model) would be large enough to be considered a peak. Peaks in charcoal accumulation rates can occur from changes in both fire regime (e.g. increased burning and more intense fires result in more charcoal) and changes in rates of charcoal deposition into lakes (Marlon *et al*. 2006; Higuera *et al*. 2007). Fourier-transform infra-red spectrometry was used to detect charcoal in peat soils and corresponded to fire events within the peat core (Uhelski 2021). It is important to note that tree-ring record detect individual fire years that correspond to fire events while lake sediment and peat records detect fire periods where multiple fires could occur in what is identified as a single fire event in the record.

We evaluated climate-fire relationships by superimposing fire years determined from tree-ring samples on a regional drought reconstruction and with superposed epoch analyses in the burnr package in R version 4.0.2 to compare regional interannual drought with the aggregated fire years from successive filtering (Grissino Mayer and Swetnam 2000, Cook *et al*. 2007). We averaged summer (June–August) Palmer Drought Severity Index (PDSI) for six PDSI grid points (206, 207, 215, 216, 224, 225) across Wisconsin and Michigan to reconstruct regional drought patterns during the period 1650–1950 when there was the most temporal overlap among tree-ring records (Cook *et al*. 2007, Falk *et al*. 2011). We analyzed climate-fire relationships for more widespread fire events that would be detected in the lake sediment and peat cores. We plotted fire years on averaged PDSI time series from 1650–1950 to evaluate climate-fire conditions (Palmer 1965). We also used superposed epoch analysis to compare climate conditions (averaged PDSI) in fire event years, and conditions prior to and following fire years, to randomly selected years from 1650–1950. We used 1000 non-parametric simulations for bootstrapped confidence intervals to assess statistical significance (p-value < 0.05) of departure from mean annual PDSI for fire years, as well as for two years prior to and after fire years (Grissino Mayer and Swetnam 2000, Malevich *et al*. 2018).

Results and Discussion

We used a multi-proxy approach to reconstruct fire histories among peatlands in the Lake States with two lake sediment cores (Fig. 4), 9 peat cores, and 220 fire-scarred tree samples (Fig. 5). Fire chronologies (number of years between first and last fire event) were longest for peat and lake sediment records (>1000 years) and shorter for tree-ring records (>100 years; Table 1). Mean fire return intervals ranged from 95 to 704 years in the lake sediment record, ranged from 324 to 392 years in the peat records, and ranged from 7 to 27 years in the tree-ring record (Table 1). Historical fire regimes in peatlands across the Lake States have largely been reconstructed using methods designed to capture infrequent high-severity fires (Whitney 1986, Cleland *et al*. 2004) resulting in fire regimes characterized by infrequent severe fires that burn thousands of hectares (Wein *et al*. 1983, Zoltai *et al*. 1998, Kasischke and Turetsky 2006). Our methods reconstructed fire regimes at multiple spatial and temporal scales to include frequent low-severity fire events, which have been largely overlooked in the Lake States (Cleland *et al*. 2004, Booth *et al*. 2004, Dickmann and Cleland 2005). Mean fire return intervals we determined from lake sediment and peat records were comparable to mean fire intervals (100–200 years) reported in the literature (Bergeron *et al*. 2004*b*, Whitney 1986, Cleland *et al*. 2004) while mean fire return intervals reconstructed with tree-ring records were orders of magnitudes shorter. Our results suggest that fire regimes across peatlands in the Lake States were characterized by both frequent low-severity fires (detected in tree-ring records) and infrequent high-severity fires (detected in lake sediment and peat records). Different methodologies contribute to disparity in historical fire return intervals reported in peatlands.

Table 1. Summary of fire histories reconstructed with lake sediment records, peat records[A], and tree-ring records among peatlands of the Lake States.

Site	Record type	Length of chronology (years)	# of samples	# of fire events[B]	Mean fire return interval (years)
Betchler Lake	Lake sediment	4221	1	7	704
	Peat	5072	5	21	392
	Tree-ring	407	62	77	21
Upper Lost Lake	Lake sediment	5047	1	54	95
	Peat	7537	4	68	324
	Tree-ring	295	41	40	27
Haymeadow Flowage	Tree-ring	159	26	25	7

[A] Peat records included in table obtained from Uhelski 2021.
[B] The temporal resolution of fire events in lake sediment and peat records ranged from 20 – 200 and the temporal resolution of fire events in tree-ring records was one year.

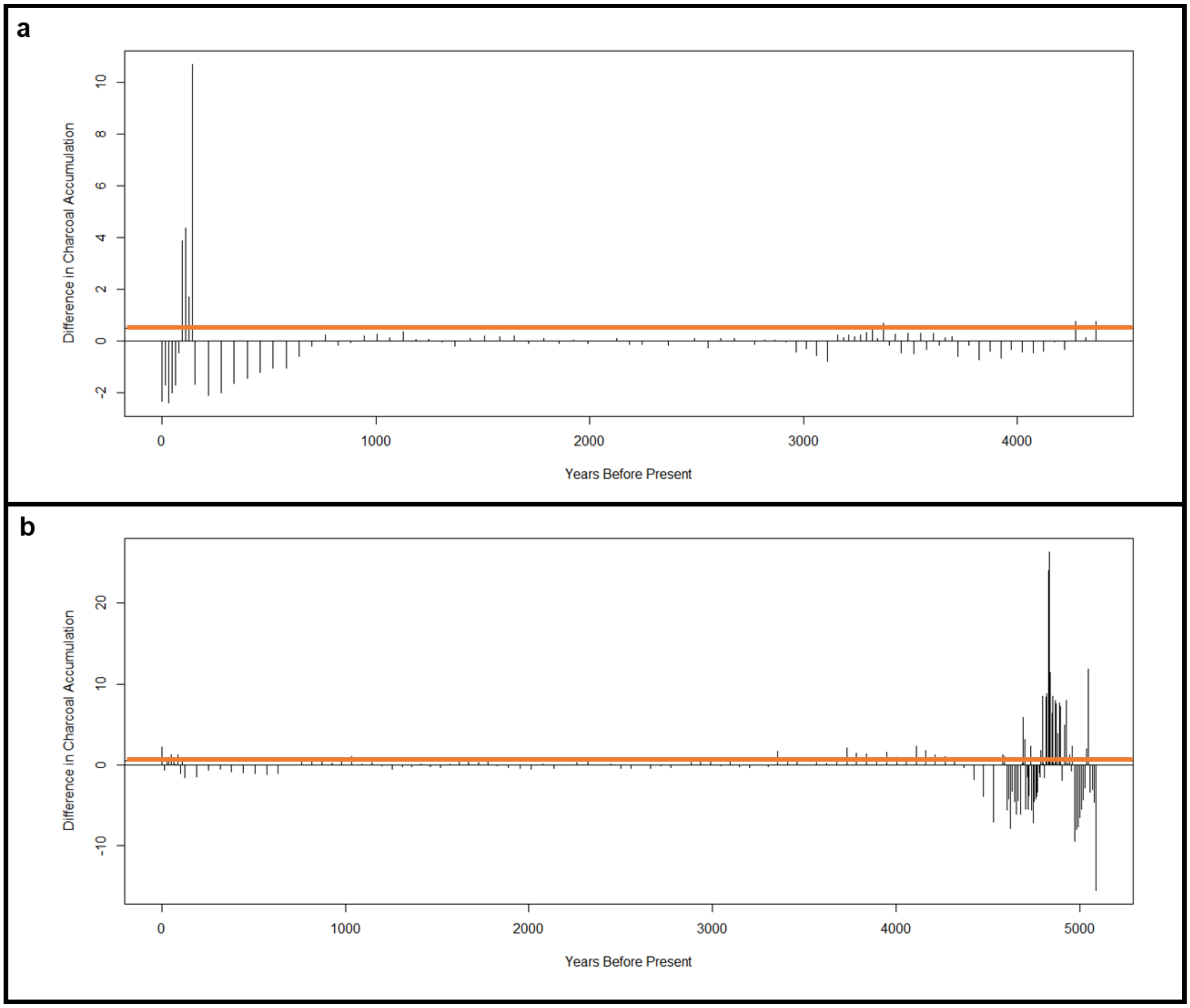

Fig. 4 Peaks in charcoal accumulation rates over time from lake sediment cores from Betchler Lake (a) and Upper Lost Lake (b). The orange line corresponds to a charcoal accumulation rate of 0.5 and was chosen to represent the threshold at which the peak indicated a fire period.

Fire years detected in the tree-ring record were synchronous and widspread (Fig. 5) indicating fires burned across peatland complexes. At Haymeadow Flowage we detected seven widespread fire years: 1845 CE, 1847 CE, 1860 CE, 1866 CE, 1868 CE, 1874 CE, and 1891 CE. At Upper Lost Lake we detected nine widespread fire years: 1718 CE, 1733 CE, 1744 CE, 1751 CE, 1754 CE, 1774 CE, 1847 CE, 1891 CE, and 1932 CE. At Betchler Lake we detected 10 widespread fire: 1735 CE, 1755 CE, 1791 CE, 1792 CE, 1861 CE, 1869 CE, 1887 CE, 1900 CE, 1907 CE, and 1920 CE. These widespread fire years detected in the tree-ring record corresponded to fire periods in lake sediment records (1880 CE – 2018 CE). Peat records did not record any fire events during the period that overlapped with the tree-ring record. Synchronous fire events in result from widespread fires (Farris *et al*. 2010) and can be used to understand and compare fire events at multiple spatial and temporal scales (Morgan *et al*. 2001, Meunier and Shea 2020). 1891 CE, which we detected in the tree-ring record and likely contributed to the fire periods we detected in lake sediment records, was a regionally significant fire year recorded by other studies across the Lake States (Drobyshev *et al*. 2008, Muzika *et al*. 2015, Meunier and Shea 2020).

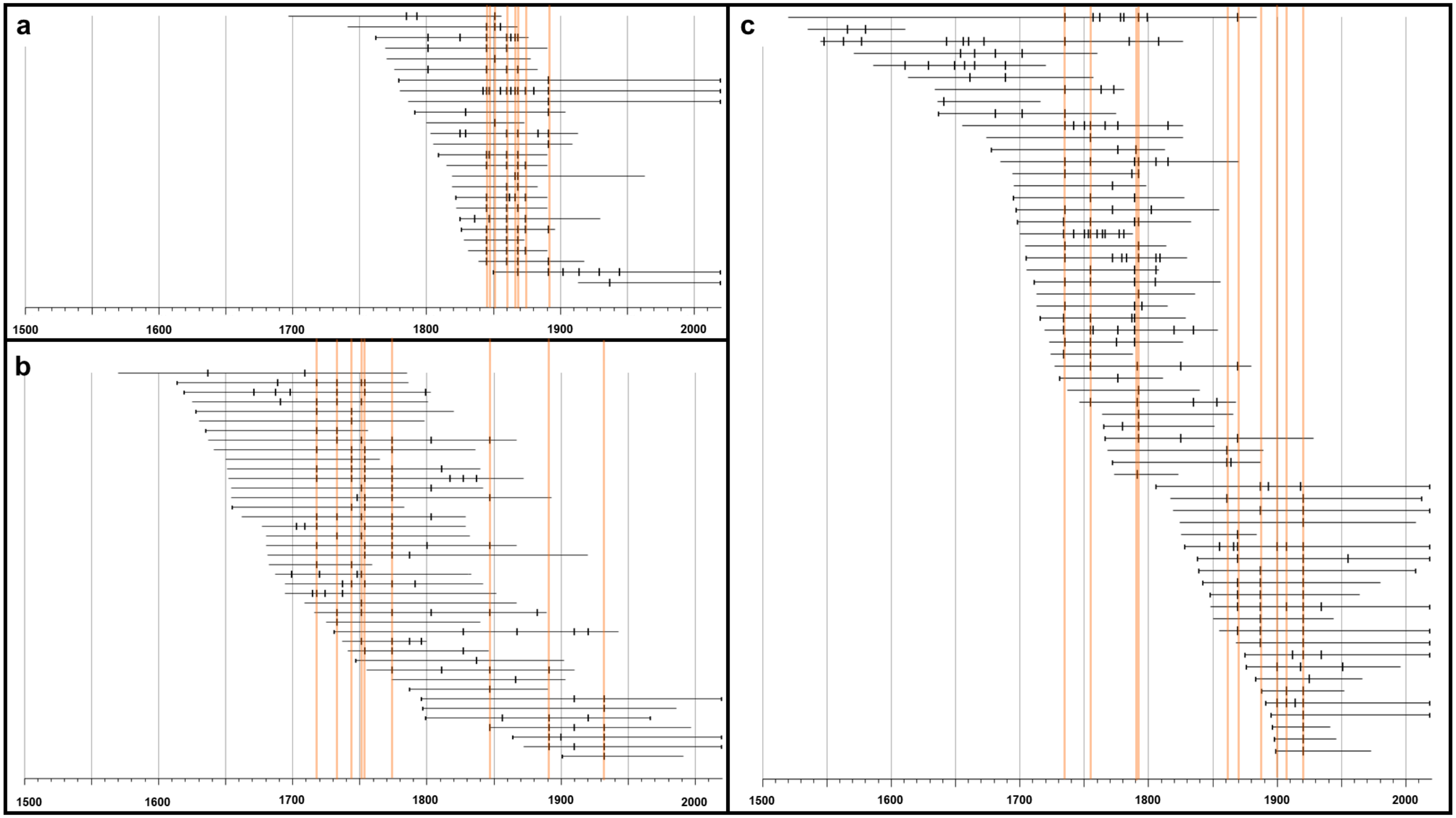

Fig. 5. Fire histories reconstructed with tree-ring records arranged by site. (a) Haymeadow Flowage, (b) Upper Lost Lake, and (c) Betchler Lake. Each horizontal line is a sample (remnant stump, standing snag, fallen snag, or living tree), longer black vertical lines are recorded fire events, and shorter black lines are pith/bark years. Orange vertical lines highlight years where fire events were recorded on more than two forested uplands within and surrounding peatlands representing widespread fire years. Years correspond to CE.

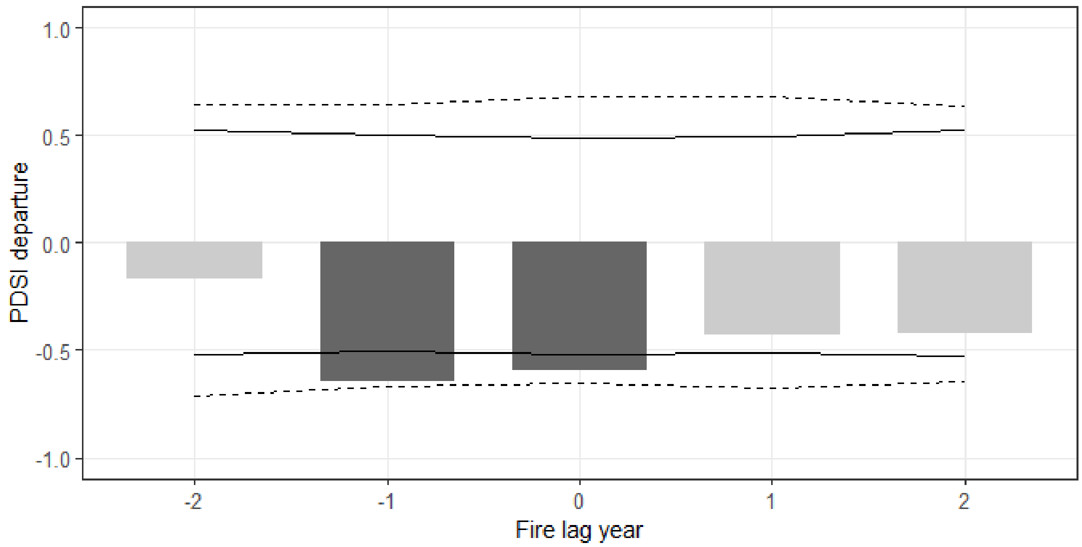

Fig. 6. Superposed epoch analysis of departure from regional average PDSI across peatlands in the Lake States during widespread fire years. Positive PDSI indicate wet conditions and negative indicate dry conditions. Dark grey bars indicate a significant departure (p-value < 0.05) from average summer PDSI. Solid horizontal lines correspond to 95% confidence interval and dashed lines are 99% confidence interval. Fire lag year 0 corresponds to years with fires detected in the tree-ring record.

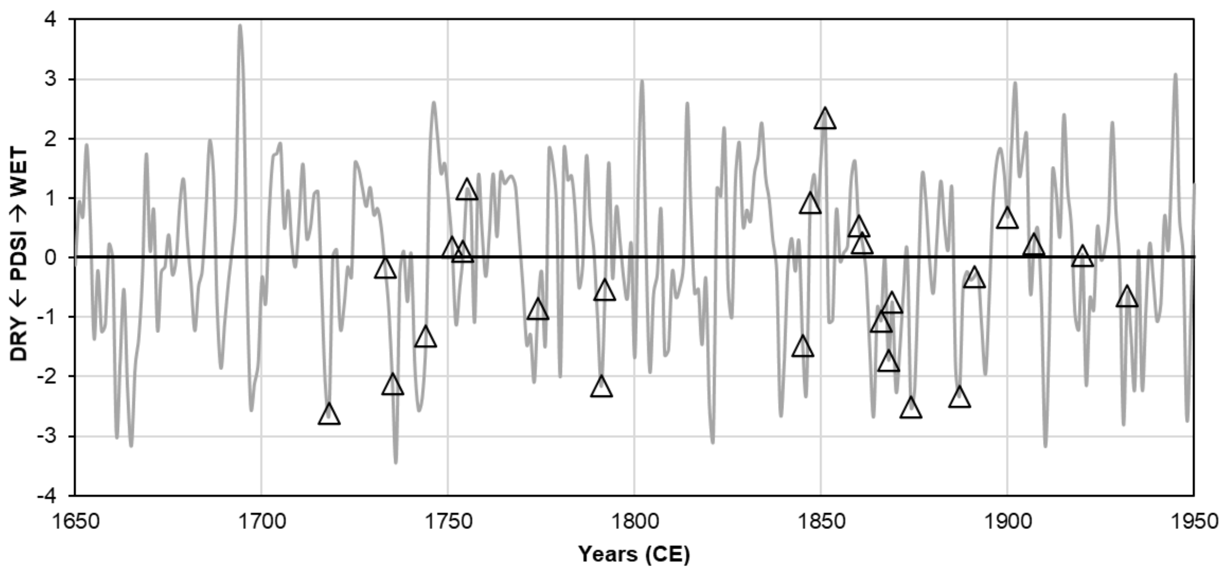

Fig. 7. Plotted average summer Palmer Drought Severity Index (PDSI; Cook *et al*. 2007) with fire years superimposed on the PDSI time series. Fire years included years detected among the peatland sites for widespread fire events that occurred on more than two forested uplands within and surrounding peatlands at each site. Positive PDSI indicate wet conditions and negative indicate dry conditions.

Somewhat counterintuitively widespread fire events detected by tree-ring records in our study sites did not occur during severe drought (Fig. 6) with 64% of widespread fire events corresponding to wet and near normal conditions (PDSI ≥ -0.49), 36% of widespread fire events corresponding to mild and moderate drought conditions (-2.99 ≤ PDSI ≤ -0.50), and 0% of widespread fire years corresponding to severe and extreme drought conditions (PDSI ≤ -3.00). However, fire years detected in the tree-ring record among peatland sites were associated with significantly (p-value < 0.05) dry conditions across all filters (Fig. 7). The year preceding fire years was also associated with significantly (p-value < 0.05) dry conditions. While somewhat surprising for peatlands, large fire years in the Lake States more generally have also occurred during moderate, but not severe, droughts (Guyette *et al*. 2016, Meunier and Shea 2020). Local and seasonal conditions, not just annual to multi-year regional drought conditions, may be a determinant of fire frequency and fire severity in peatlands.

Fire-vegetation-climate interactions in peatlands, specifically in relation to frequent widespread low-severity fire events, are strongly influenced by short-term seasonal drying, forest composition, and fire ecology of species, but not by severe regional droughts. Climatically driven fire regimes characterized by high-severity fire are an important part of peatland landscapes in the Lake States (Heinselman 1965, Whitney 1986) and climate reconstructions over the temporal extent peat and lake sediment records could likely provide further insights to these climate patterns especially at the regional scale. While climate effects are often broad in scale, localized influences of plant species and ecosystem processes can also have strong influences on fire regime characteristics (Scheller and Mladenoff 2005, Loudermilk *et al*. 2013, Walker *et al*. 2020). Disparity among drivers of fire dynamics at fine and broad scales across the Lake States has relevant implications for peatlands and more widely across the entire region (Sedano and Randerson 2014) such that species composition, species diversity, species adaptation, climate, and landscape heterogeneity shape fire regimes across spatial and temporal scales. This was especially evident in our assessment of morphotypes of charcoal where we detected variability in fuel types including both grass species and components of pine species including wood, needles, and branches being a large percentage of types of charcoal detected during the peaks in the lake sediment records that overlapped with the tree-ring record (Fig. 8).

Science delivery

We shared our research widely including at state conferences and national conferences including the Association for Fire Ecology International Fire Ecology and Management Congress. We communicated directly with forest and fire managers in the Chequamegon-Nicolet, Hiawatha, and Ottawa National Forests and shared research updates at leadership meetings and the Great Lakes Indian Forest and Wildlife Commissions' Tribal/Forest Service annual meeting. We worked closely with ecologists in Wisconsin DNR NHC program and the MNFI who incorporated our research to support prescribed fire and managed wildfire use in natural communities. We worked with the Lake States Fire Science Consortium to present at their Annual Burning Issues Workshop and received a grant to sponsor an undergraduate intern to conduct the lake sediment work. We published a portion of this research as an open access article in Forest Ecology and Management and are preparing manuscripts for International Journal of Wildland Fire and Ecosphere. We are contributing to a North American fire scar project and a Lake States Fire History project synthesizing the current state of knowledge of fire history throughout North American and the Lake States.

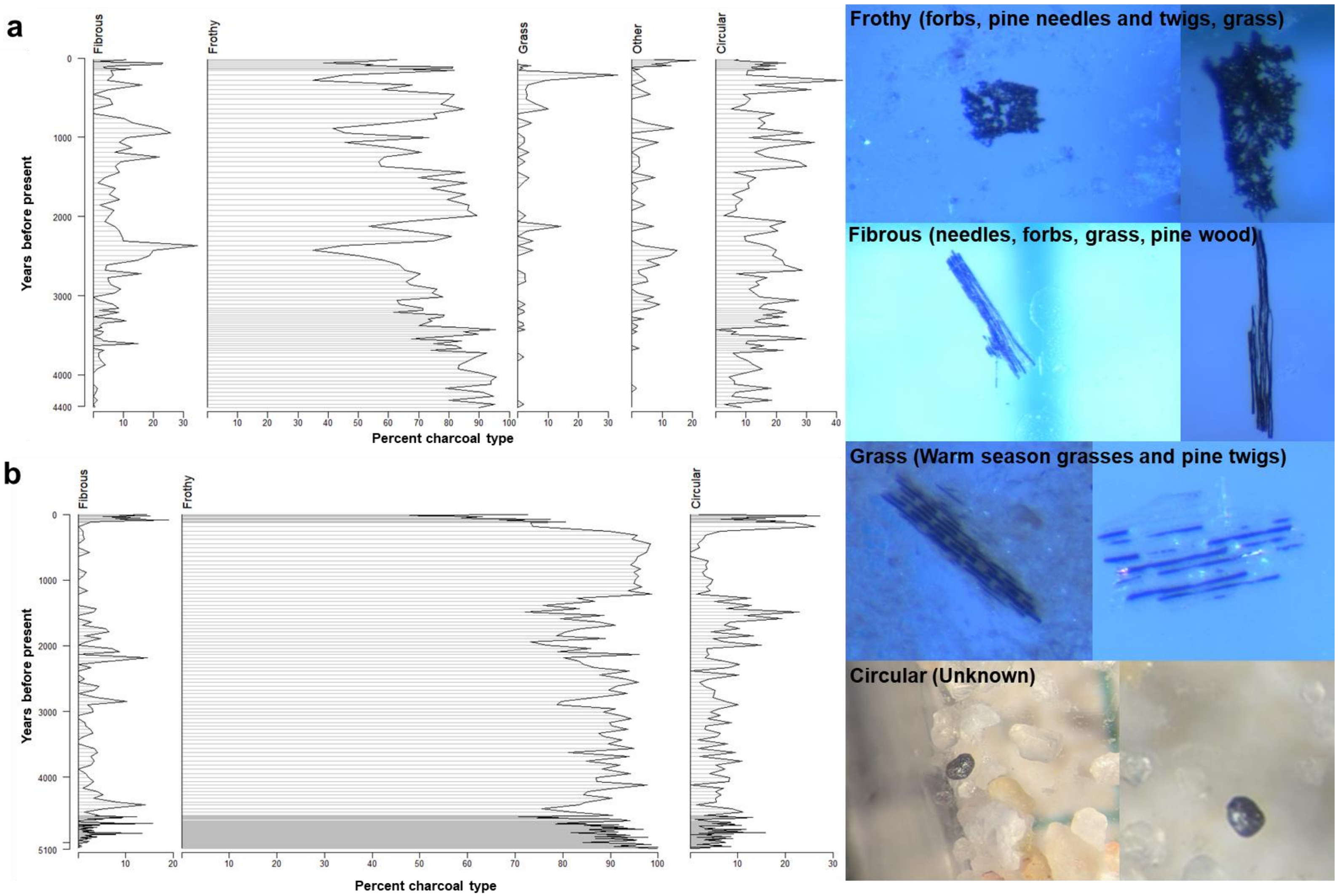

Fig. 8 Percent abundance of charcoal morphotypes over time in lake sediment cores from Betchler Lake (a) and Upper Lost Lake (b). Photographs of most abundant mophotypes are displayed with a description of vegetation that yields that charcoal morphotype when burned in laboratory settings (Jensen *et al.* 2007; Sutheimer 2007; Kaplon 2021).

Conclusions

While the role of fire varies widely around the globe (Zoltai *et al*. 1998), frequent and widespread low-severity fire events play an integral part in the maintenance of many ecosystems including reducing encroachment by woody and non-peatland vegetation. This was evident in the peatlands we studied with high abundances of fire-adapted plant communities (red and jack pine forests) and evidence of frequent and widespread low-severity fire events historically (fire-scarred trees on forested upland islands within expansive peatlands). Species composition (high proportion of fire-adapted species like *Pinus resinosa*), fuel patterning, and localized drying likely maintained historical fire regimes in peatlands and across the Lake States. Local variability in fire frequencies is influenced by natural and anthropogenic ignition sources and barriers to fire spread (Falk *et al*. 2011). Altered fire regimes, related to both increasingly severe fires driven by climate change and suppression of frequent and widespread low-severity fire, may destabilize ecosystems making them more vulnerable to climate change and future disturbances including peatlands (Flanagan *et al*. 2020). Peatlands in the Lake States are among the most vulnerable ecosystems under future climate change (Dahl 2011, Angel *et al*. 2018) and understanding the role of fire in relation to resilience over multiple spatial and temporal scales is a necessary first step to determine how they will be affected by, and contribute to, a warming world.

We conducted one of the first multi-proxy fire history reconstructions in the Lake States and we found that historical disturbance regimes across the Lake States were characterized by frequent, low severity, and widespread fires with infrequent, stand-replacing fires. Historically, climate synchronized fire events in peatlands with low- and moderate-severity fire events detected in the tree-ring record rarely corresponded to severe drought conditions. We addressed an important knowledge gap and contributed to a growing base of applicable research that is specific to peatlands and contributes more broadly to the region. We examined temporal and spatial correspondence between historical fire regimes in a way that approached fire ecology in the Lake States at varying spatial, temporal, and biophysical extents within sites and across large landscapes. These approaches are essential to providing guidance to managers at relevant scales. While prescribed fire has been widely adopted, its use in ecosystems like peatlands and forests has been minimal in part because of a lack of understanding of fire ecology. Our research supports the use of prescribed low-severity fire across the Lake States and indicates that prescribed fire could contribute to the persistence of ecosystems including poor fens and mixed-pine forests and fire-dependent species like red pine. We have provided a better understanding of fire ecology in the Lake States generally and peatlands specifically equipping managers and policy makers across the region with new information to better restore, conserve, and manage the unique ecosystems of the Lake States.

Investigating the impact of altered disturbance regimes on ecosystem processes and patterns is paramount in assessing the vulnerability of diverse ecosystems of the Lake States to continued climate change, land use changes, and novel disturbances. Extensive networks that include tree-ring, sediment, and historical records establish historical ranges of variability in disturbance regimes within and among ecosystems revealing the influence of both local and broad scale drivers on fire regimes. Integrating these records with predictive models will provide the best insights to the capacity of ecosystems to recover and persist under broad scale, highly variable climate changes.

Literature cited

Angel JR, Swanson C, Boustead BM, Conlon K, Hall KR, Jorns JL, Kunkel KE, Lemos MC, Lofgren BM, Ontl T, Posey J, Stone K, Takle E, Todey D (2018) Chapter 21 : Midwest. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program, doi:10.7930/NCA4.2018.CH21.

Barnett K, Parks S, Miller C, Naughton H (2016) Beyond Fuel Treatment Effectiveness: Characterizing Interactions between Fire and Treatments in the US. *Forests* **7**, 237. doi:10.3390/f7100237.

Bergeron Y, Brisson J (1990) Fire Regime in Red Pine Stands at the Northern Limit of the Species' Range. Ecology **71**, 1352–1364. doi:10.2307/1938272.

Bergeron Y, Flannigan M, Gauthier S, Leduc A, Lefort P (2004*a*) Past, Current and Future Fire Frequency in the Canadian Boreal Forest: Implications for Sustainable Forest Management. *Ambio* **33**, 356–360.

Bergeron Y, Gauthier S, Flannigan M, Kafka V (2004*b*) Fire regimes at the transition between mixedwood and coniferous boreal forests at in northwestern Quebec. **85**, 17.

Blaauw M, Christen JA (2011) Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis* **6**,. doi:10.1214/11-BA618.

Booth RK, Jackson ST (2003) A high-resolution record of late-Holocene moisture variability from a Michigan raised bog, USA. *The Holocene* **13**, 863–876. doi:10.1191/0959683603hl669rp.

Booth RK, Jackson ST, Gray CED (2004) Paleoecology and high-resolution paleohydrology of a kettle peatland in upper Michigan. *Quaternary Research* **61**, 1–13. doi:10.1016/j.yqres.2003.07.013.

Brandt JP (2009) The extent of the North American boreal zone. *Environmental Reviews* **17**, 101–161. doi:10.1139/A09-004.

Brossier B, Oris F, Finsinger W, Asselin H, Bergeron Y, Ali AA (2014) Using tree-ring records to calibrate peak detection in fire reconstructions based on sedimentary charcoal records. *The Holocene* **24**, 635–645. doi:10.1177/0959683614526902.

Cleland DT, Crow TR, Saunders SC, Dickmann DI, Maclean AL, Jordan JK, Watson RL, Sloan AM, Brosofske KD (2004) Characterizing historical and modern fire regimes in Michigan (USA): A landscape ecosystem approach. *Landscape Ecology* **19**, 311–325. doi:10.1023/B:LAND.0000030437.29258.3c.

Cohen JG, Slaughter BS, Kost MA, Albert DA (2015) 'A field guide to the natural communities of Michigan.' (Michigan State University Press: East Lansing, Michigan)

Cook ER, Seager R, Cane MA, Stahle DW (2007) North American drought: Reconstructions, causes, and consequences. *Earth-Science Reviews* **81**, 93–134. doi:10.1016/j.earscirev.2006.12.002.

Cyr D, Gauthier S, Bergeron Y (2007) Scale-dependent determinants of heterogeneity in fire frequency in a coniferous boreal forest of eastern Canada. *Landscape Ecology* **22**, 1325–1339. doi:10.1007/s10980-007-9109-3.

Dahl TE (2011) Status and Trends of Wetlands in the Conterminous United States 2004 to 2009.

Dickmann DI, Cleland DT (2005) Fire Return Intervals and Fire Cycles for Historic Fire Regimes in the Great Lakes Region: A Synthesis of the Literature. United States Forest Service, 98-1-5–03. https://www.firescience.gov/projects/98-1-5-03/project/98-1-5-03_98_1_5_03_lsfirecycles.pdf.

Drobyshev I, Goebel PC, Hix DM, Corace RG, Semko-Duncan ME (2008) Pre- and post-European settlement fire history of red pine dominated forest ecosystems of Seney National Wildlife Refuge, Upper Michigan. *Canadian Journal of Forest Research* **38**, 2497–2514. doi:10.1139/X08-082.

Falk DA, Heyerdahl EK, Brown PM, Farris C, Fulé PZ, McKenzie D, Swetnam TW, Taylor AH, Horne MLV (2011) Multi-scale controls of historical forest-fire regimes: new insights from fire-scar networks. Frontiers in Ecology and the Environment 9, 446–454. doi:10.1890/100052.

Farris CA, Baisan CH, Falk DA, Van Horne ML, Fulé PZ, Swetnam TW (2013) A comparison of targeted and systematic fire-scar sampling for estimating historical fire frequency in south-western ponderosa pine forests. *International Journal of Wildland Fire* **22**, 1021. doi:10.1071/WF13026.

Farris CA, Baisan CH, Falk DA, Yool SR, Swetnam TW (2010) Spatial and temporal corroboration of a fire-scar-based fire history in a frequently burned ponderosa pine forest. *Ecological Applications* **20**, 1598–1614. doi:10.1890/09-1535.1.

Flanagan NE, Wang H, Winton S, Richardson CJ (2020) Low-severity fire as a mechanism of organic matter protection in global peatlands: Thermal alteration slows decomposition. *Global Change Biology* **26**, 3930–3946. doi:10.1111/gcb.15102.

Grissino-Mayer HD, Swetnam TW (2000) Century scale climate forcing of fire regimes in the American Southwest. *The Holocene* **10**, 213–220. doi:10.1191/095968300668451235.

Guyette R, Stambaugh M, Dey D, Marschall J, Saunders J, Lampereur J (2016) 350 Years of Fire-Climate-Human Interactions in a Great Lakes Sandy Outwash Plain. *Forests* **7**, 189. doi:10.3390/f7090189.

Heinselman ML (1963) Forest Sites, Bog Processes, and Peatland Types in the Glacial Lake Agassiz Region, Minnesota. *Ecological Monographs* **33**, 327–374. doi:10.2307/1950750.

Heinselman ML (1973) Fire in the Virgin Forests of the Boundary Waters Canoe Area, Minnesota. *Quaternary Research* **3**, 329–382. doi:10.1016/0033-5894(73)90003-3.

Higuera PE, Gavin DG, Bartlein PJ, Hallett DJ (2010) Peak detection in sediment-charcoal records: impacts of alternative data analysis methods on fire-history interpretations. *International Journal of Wildland Fire* **19**, 996–1014.

Higuera P, Peters M, Brubaker L, Gavin D (2007) Understanding the origin and analysis of sediment-charcoal records with a simulation model. *Quaternary Science Reviews* **26**, 1790–1809. doi:10.1016/j.quascirev.2007.03.010.

Higuera PE, Whitlock C, Gage JA (2011) Linking tree-ring and sediment-charcoal records to reconstruct fire occurrence and area burned in subalpine forests of Yellowstone National Park, USA. *The Holocene* **21**, 327–341. doi:10.1177/0959683610374882.

Jensen K, Lynch EA, Calcote R, Hotchkiss SC (2007) Interpretation of charcoal morphotypes in sediments from Ferry Lake, Wisconsin, USA: do different plant fuel sources produce distinctive charcoal morphotypes? *The Holocene* **17**, 907–915. doi:10.1177/0959683607082405.

Johnson EA, & Gutsell SL (1994) Fire Frequency Models, Methods and Interpretations. *Advances in Ecological Research* **25**, 239–287.

Kane ES, Turetsky MR, Harden JW, McGuire AD, Waddington JM (2010) Seasonal ice and hydrologic controls on dissolved organic carbon and nitrogen concentrations in a boreal-rich fen. *Journal of Geophysical Research* **115**,. doi:10.1029/2010JG001366.

Kaplon, C (2021) Analyzing Charcoal Morphotypes and Fire Events in Lower Betchler Lake. (Unpublished bachelor’s thesis, University of Wisconsin-Madison, Madison, WI USA)

Kasischke ES, Turetsky MR (2006) Recent changes in the fire regime across the North American boreal region—Spatial and temporal patterns of burning across Canada and Alaska. *Geophysical Research Letters* **33**, L09703. doi:10.1029/2006GL025677.

Kelly R, Chipman ML, Higuera PE, Stefanova I, Brubaker LB, Hu FS (2013) Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. *Proceedings of the National Academy of Sciences* **110**, 13055–13060. doi:10.1073/pnas.1305069110.

Loudermilk EL, Scheller RM, Weisberg PJ, Yang J, Dilts TE, Karam SL, Skinner C (2013) Carbon dynamics in the future forest: the importance of long-term successional legacy and climate-fire interactions. *Global Change Biology* n/a-n/a. doi:10.1111/gcb.12310.

Lynch EA, Calcote R, Hotchkiss SC, Tweiten M (2014) Presence of lakes and wetlands decreases resilience of jack pine ecosystems to late-Holocene climatic changes. Canadian Journal of Forest Research 44, 1331–1343. doi:10.1139/cjfr-2014-0107.

Lynch EA, Hotchkiss SC, Calcote R (2011) Charcoal signatures defined by multivariate analysis of charcoal records from 10 lakes in northwest Wisconsin (USA). *Quaternary Research* **75**, 125–137. doi:10.1016/j.yqres.2010.08.007.

Marlon JR, Bartlein PJ, Gavin DG, Long CJ, Anderson RS, Briles CE, Brown KJ, Colombaroli D, Hallett DJ, Power MJ, Scharf EA, Walsh MK (2012) Long-term perspective on wildfires in the western USA. *Proceedings of the National Academy of Sciences* **109**, E535–E543. doi:10.1073/pnas.1112839109.

Malevich SB, Guiterman CH, Margolis EQ (2018) burnr: Fire history analysis and graphics in R. *Dendrochronologia* **49**, 9–15. doi:10.1016/j.dendro.2018.02.005.

McLauchlan KK, Higuera PE, Miesel J, Rogers BM, Schweitzer J, Shuman JK, Tepley AJ, Varner JM, Veblen TT, Adalsteinsson SA, Balch JK, Baker P, Batllori E, Bigio E, Brando P, Cattau M, Chipman ML, Coen J, Crandall R, Daniels L, Enright N, Gross WS, Harvey BJ, Hatten JA, Hermann S, Hewitt RE, Kobziar LN, Landesmann JB, Loranty MM, Maezumi SY, Mearns L, Moritz M, Myers JA, Pausas JG, Pellegrini AFA, Platt WJ, Roozeboom J, Safford H, Santos F, Scheller RM, Sherriff RL, Smith KG, Smith MD, Watts AC (2020) Fire as a fundamental ecological process: Research advances and frontiers (G Durigan, Ed.). *Journal of Ecology* **108**, 2047–2069. doi:10.1111/1365-2745.13403.

Meunier J, Holoubek NS, Brown PM, Sebasky M (2019a) Re-evaluating pattern and process to understand resilience in transitional mixed conifer forests. Ecology 100, e02839. doi:10.1002/ecy.2839.

Meunier J, Holoubek NS, Sebasky M (2019b) Fire regime characteristics in relation to physiography at local and landscape scales in Lake States pine forests. Forest Ecology and Management 454, 117651. doi:10.1016/j.foreco.2019.117651.

Meunier J, Shea ME (2020) Applying the usual rules to an unusual ecological situation: Fire rotation in Great Lakes Pine Forests. *Forest Ecology and Management* **472**, 118246. doi:10.1016/j.foreco.2020.118246.

Miesel J, Goebel P, Corace R, Hix D, Kolka R, Palik B, Mladenoff D (2012) Fire Effects on Soils in Lake States Forests: A Compilation of Published Research to Facilitate Long-Term Investigations. *Forests* **3**, 1034–1070. doi:10.3390/f3041034.

Minnesota Department of Natural Resources (2003) 'Field Guide to the native plant communities of Minnesota: the Laurentian Mixed Forest Province.' (Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program: St. Paul, MN)

Morgan P, Hardy CC, Swetnam TW, Rollins MG, Long DG (2001) Mapping fire regimes across time and space: Understanding coarse and fine-scale fire patterns. *International Journal of Wildland Fire* **10**, 329. doi:10.1071/WF01032.

Muzika RM, Guyette RP, Stambaugh MC, Marschall JM (2015) Fire, Drought, and Humans in a Heterogeneous Lake Superior Landscape. *Journal of Sustainable Forestry* **34**, 49–70. doi:10.1080/10549811.2014.973991.

Palmer WC (1965) Meteorological Drought. U.S. Weather Bureau, Research Paper No. 45 (Washington D.C.)

Plante AF, Fernandez JM, Leifeld J (2009) Application of thermal analysis techniques in soil science. *Geoderma* **153**, 1–10. doi:10.1016/j.geoderma.2009.08.016.

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, Bronk Ramsey C, Butzin M, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg AG, Hughen KA, Kromer B, Manning SW, Muscheler R, Palmer JG, Pearson C, van der Plicht J, Reimer RW, Richards DA, Scott EM, Southon JR, Turney CSM, Wacker L, Adolphi F, Büntgen U, Capano M, Fahrni SM, Fogtmann-Schulz A, Friedrich R, Köhler P, Kudsk S, Miyake F, Olsen J, Reinig F, Sakamoto M, Sookdeo A, Talamo S (2020) The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* **62**, 725–757. doi:10.1017/RDC.2020.41.

Remy CC, Fouquemberg C, Asselin H, Andrieux B, Magnan G, Brossier B, Grondin P, Bergeron Y, Talon B, Girardin MP, Blarquez O, Bajolle L, Ali AA (2018) Guidelines for the use and interpretation of palaeofire reconstructions based on various archives and proxies. *Quaternary Science Reviews* **193**, 312–322. doi:10.1016/j.quascirev.2018.06.010.

Scheller RM, Mladenoff DJ (2005) A spatially interactive simulation of climate change, harvesting, wind, and tree species migration and projected changes to forest composition and biomass in northern Wisconsin, USA. *Global Change Biology* **11**, 307–321. doi:10.1111/j.1365-2486.2005.00906.x.

Schulte LA, Mladenoff DJ (2005) Severe wind and fire regimes in northern forests: Historical variability at the regional scale. *Ecology* **86**, 431–445. doi:10.1890/03-4065.

Schulte LA, Mladenoff DJ, Crow TR, Merrick LC, Cleland DT (2007) Homogenization of northern U.S. Great Lakes forests due to land use. *Landscape Ecology* **22**, 1089–1103. doi:10.1007/s10980-007-9095-5.

Sedano F, Randerson JT (2014) Multi-scale influence of vapor pressure deficit on fire ignition and spread in boreal forest ecosystems. *Biogeosciences* **11**, 3739–3755. doi:10.5194/bg-11-3739-2014.

Speer JH (2010) 'Fundamentals of tree-ring research.' (Univ. of Arizona Press: Tucson, Ariz)

Sutheimer, CM (2007) Vegetation and fire history from Lone Star (Saunder's) Lake, Burnett County, Wisconsin. (Unpublished bachelor's thesis, University of Wisconsin-Madison, Madison, WI USA)

Swetnam TW, Farella J, Roos CI, Liebmann MJ, Falk DA, Allen CD (2016) Multiscale perspectives of fire, climate and humans in western North America and the Jemez Mountains, USA. *Philosophical Transactions of the Royal Society B: Biological Sciences* **371**, 20150168. doi:10.1098/rstb.2015.0168.

Uhelski, D (2021) Elucidating peatland disturbance ecology and carbon dynamics through the lens of soil using infrared spectrometry. (Doctoral dissertation, Michigan Technological University, Houghton, MI, USA)

Van Wagner CE (1978) Age-class distribution and the forest fire cycle. *Canadian Journal of Forest Research* **8**, 220–227. doi:10.1139/x78-034.

Walker XJ, Rogers BM, Veraverbeke S, Johnstone JF, Baltzer JL, Barrett K, Bourgeau-Chavez L, Day NJ, de Groot WJ, Dieleman CM, Goetz S, Hoy E, Jenkins LK, Kane ES, Parisien M-A, Potter S, Schuur EAG, Turetsky M, Whitman E, Mack MC (2020) Fuel availability not fire weather controls boreal wildfire severity and carbon emissions. *Nature Climate Change* **10**, 1130–1136. doi:10.1038/s41558-020-00920-8.

Wein RW, MacLean DA, International Council of Scientific Unions (Eds) (1983) 'The Role of fire in northern circumpolar ecosystems.' (Published on behalf of the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions by Wiley: Chichester [West Sussex]; New York)

Whitney GG (1986) Relation of Michigan's Presettlement Pine Forests to Substrate and Disturbance History. *Ecology* **67**, 1548–1559. doi:10.2307/1939085.

Wilkinson SL, Moore PA, Flannigan MD, Wotton BM, Waddington JM (2018) Did enhanced afforestation cause high severity peat burn in the Fort McMurray Horse River wildfire? *Environmental Research Letters* **13**, 014018. doi:10.1088/1748-9326/aaa136.

Zoltai SC, Morrissey LA, Livingston GP, de Groot WJ (1998) Effects of fires on carbon cycling in North American boreal peatlands. **6**, 13.

Appendix A: Contact Information for Key Project Personnel

Volker C. Radeloff
SILVIS Lab, Department of Forest and Wildlife Ecology, University of Wisconsin, 1630 Linden Drive, Madison, Wisconsin 53706 USA; radeloff@wisc.edu; 16082634349

Sara C. Hotchkiss
Botany Department, University of Wisconsin, 430 Lincoln Drive, Madison, Wisconsin 53706 USA; shochkiss@wisc.edu; 16082656751

Jed Meunier
Wisconsin Department of Natural Resources, Division of Forestry, 2801 Progress Road, Madison, Wisconsin 53716 USA; jed.meunier@wisconsin.gov; 16082357321

Colleen M. Sutheimer
SILVIS Lab, Department of Forest and Wildlife Ecology, University of Wisconsin, 1630 Linden Drive, Madison, Wisconsin 53706 USA; sutheimer@wisc.edu; 16082795742

Appendix B: List of Completed/Planned Products

Graduate thesis
Sutheimer, C.M. August 2021. Historical fire regimes of the upper Great Lakes Region: From peatlands to pines. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Forestry at the University of Wisconsin-Madison.

Article in peer-reviewed journals
Sutheimer, C.M., J. Meunier, S.C. Hotchkiss, E. Rebitzke, and V.C. Radeloff. Historical fire regimes of North American hemiboreal peatlands (2021) *Forest Ecology and Management **498**, 119561*.

Sutheimer, C.M., J. Meunier, and V.C. Radeloff. Widespread fire years across disparate ecoregions of the upper Great Lakes Region, USA. *International Journal of Wildland in Fire (in preparation).*

Margolis, E.M., C.H. Guiterman ……C.M. Sutheimer. The North American tree-ring fire-scar network. 2021. *Ecosphere (in preparation).*

Presentations
Sutheimer, C.M. Rethinking peatland fire: Fire history of peatlands in the Great Lakes Region. Presented virtually at the 2021 Lake States Fire Science Consortium Annual Burning Issues Workshop and Michigan Prescribed Fire Council.

Sutheimer, C.M. Reconstructing fire history in peatlands and the Great Lakes. Presented virtually at the 2020 Great Lakes Indian Forest and Wildlife Commission's Tribal and Forest Service annual meeting.

Sutheimer, C.M., J. Meunier, and E. Rebitzke. Ecosystem departure and fire history analysis. Presented research update at the 2020 Hiawatha National Forest leadership team meeting in Gladstone, MI.

Sutheimer, C.M., J. Meunier, and E. Rebitzke. Ecosystem departure and fire history analysis. Presented research at the 2020 Ottawa National Forest leadership team meeting in Ironwood, MI.

Posters

Sutheimer, C.M., J. Meunier, S.C. Hotchkiss, and V.C. Radeloff. Fire in forested peatlands of the upper Great Lakes: Reconstructing past disturbance for conservation. Presented at the 2020 Association for Fire Ecology International Fire Ecology and Management Congress in Tucson, AZ.

Appendix C: Metadata:

Metadata pertaining to fire-scarred tree samples, lake sediment cores, lake sediment core radiocarbon dating, and lake sediment core lead-210 dating have all been uploaded to the JFSP database in the final reports tab. We have also included partial metadata for peat cores, but this data was provided to us by Dr. Dominic Uhelski and was not obtained as part of this JFSP funded project. The storage of fire-scarred tree sample and lake sediment core data in repositories is described below.

Fire-scarred tree samples

Physical fire-scarred tree samples and associated files of electronic scans are currently archived at the Wisconsin DNR Science Operation Center, 2801 Progress Road, Madison, WI, 53716 Phone: 608-221-6320

Fire history metadata and data will be deposited with the National Oceanic and Atmospheric Administration Multiproxy Paleofire Database (IMPD) which serves as a permanent repository for high-quality paleofire records from around the world. This database was chosen rather than the International Tree-ring Data Bank because it is a more appropriate repository for the type of data we produced during this study and because we can submit both our tree-ring records and lake sediment records to this repository. We will also provide fire history metadata and data to the Forest Service Research Data Archive. All data will be submitted by March 2022.

Lake sediment cores

Physical lake sediment core halves and all associated metadata for the lake sediment cores in this study are archived at the National Lacustrine Core Repository in the National Lacustrine Core Facility at the University of Minnesota, 116 Church Street SE, Minneapolis, MN 55455 Phone: 612-626-7889. Lake sediment core fire history metadata and data will be deposited with the National Oceanic and Atmospheric Administration Multiproxy Paleofire Database (IMPD) and the Forest Service Research Data Archive. All data will be submitted by March 2022.